§2. Nonlinear Evolution of the Toroidicity-induced Alfvén Eigenmodes

Todo, Y., Sato, T.

The toroidicity-induced Alfvén eigenmode (TAE) is a shear-Alfvén eigenmode in toroidal plasmas. TAEs have been observed in many experiments such as the neutral beam injection (NBI) experiments, the ion-cyclotron-range-of-frequency (ICRF) heating experiments, and D-T fusion experiments in the TFTR. Nonlinear evolution of TAEs is an important issue for fusion reactors, since TAEs with sufficiently large amplitude induce fast-ion losses. In NBI experiments TAEs show a recurrent bursting behavior. Much attention should be paid to that they show a coherent behavior. In the ICRF heating experiments and D-T fusion experiments in the TFTR, TAEs persist much longer than the typical damping time.

Although many computational simulations of TAEs have been carried out, neither pulsating behavior or steady saturation have been reproduced. What seems to be lacking in the past simulations is to incorporate the distribution-forming-processes of fast ions, such as particle source, slowing down, pitch-angle scattering, and wave heating. As the first step towards a comprehensive simulation, we incorporate particle source and slowing down for fast ions in the Vlasov-MHD simulation code [1]. Time evolution of the fast-ion distribution function in a four-dimensional phase space (three-dimensional real space and one-dimensional velocity space for the parallel velocity) is followed by a finite difference method. The pitch-angle scattering and wave heating are not considered in the present study.

In the model employed here, plasma is divided into two parts, the background plasma and fast ions. The background plasma is described by the magnetohydrodynamic (MHD) equations and the electromagnetic field is given by the MHD description. A finite viscosity $\nu=2\times10^{-5}v_A R_0$ is considered to realize mode damping. It yields, for example, an e-folding damping time of $130\tau_A$ for an $n=2$ TAE which is the most unstable mode in the simulations described below. The full magnetohydrodynamic equations are solved by a finite difference method of a forth-order accuracy in space and time.

Simulation results are summarized as follows [2]:

1. When the time scale of the distribution-forming-process [the slowing-down time in the present study] is comparable to the damping time, TAEs persist after saturation with steady amplitudes [Fig. 1].
2. When the time scale of the distribution-forming-process is longer than the damping time, the amplitudes of TAEs are not at steady levels. Especially, when the fast-ion pressure is sufficiently high, multiple TAEs show a coherent pulsating behavior [Fig. 2].
3. The pulsating behavior is similar to that observed in NBI heating experiments. In this case, the fast-ion distribution function is globally flattened due to the overlapped many TAEs. This global flattening will explain the fast-ion losses observed at the NBI heating experiments. The steady saturation found in the simulation with the short slowing-down time is also interesting if we compare it to the ICRF experiments.

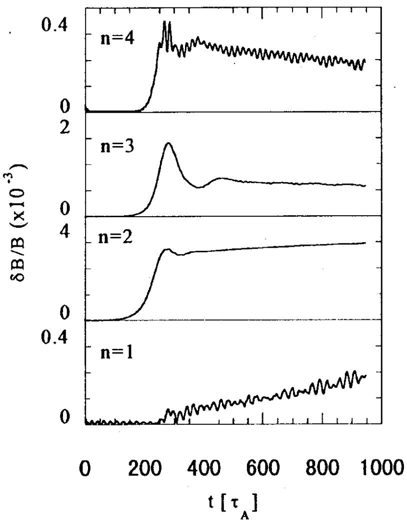

Fig. 1. Time history of m/n = *2/1, 3/2, 4/3, 6/4* harmonics for low fast ion pressure and short slowing-down time.

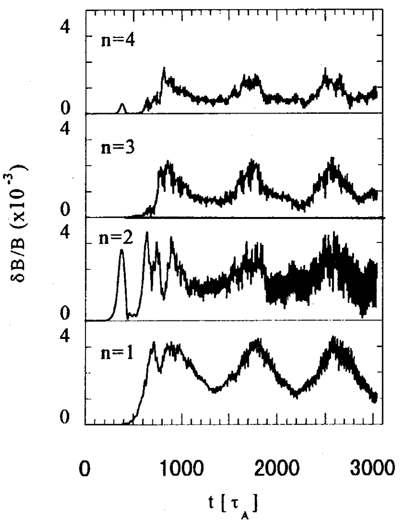

Fig. 2. Time history of the harmonics for high fast ion pressure and long slowing-down time.

References

[1] Y. Todo *et al.*, Phys. Plasmas **2**, 2711 (1995).

[2] Y. Todo and T. Sato, in "Theory of Fusion Plasmas" (Societa Italiana di Fisica, 1999), 229.